Estimating Total Population Size for Songbirds[1]

Jonathan Bart[2]

Introduction

A conviction has developed during the past few years within the avian conservation community that estimates of total population size are needed for many species, especially ones that warrant conservation action. For example, the recently completed monitoring plans for North American shorebirds and landbirds establish estimating population size as a major objective. Obtaining these estimates rigorously, however, is difficult. Rosenberg and Blancher (this volume) describe one approach that generates point estimates based on several assumptions. Here, I describe an alternate approach which incorporates uncertainty about the assumptions and establishes a range for the true population size. It is illustrated by estimating population size for four shrubsteppe species across a large portion of their range using Breeding Bird Survey (BBS) data.

The BBS consists of roadside routes randomly selected within one-degree blocks throughout the United States (except Hawaii) and southern Canada. Each route has 50 stations regularly spaced at 0.5-mile intervals, and is surveyed once during the breeding season (mainly in June) starting 30 minutes before dawn. Observers record all birds detected for 3 minutes at each station. The Survey has been widely hailed as one of the best wildlife monitoring programs in the world (e.g. Ralph et al. 1995). Its results are used each year in dozens of publications for both applied and theoretical purposes (Sauer et al. 1999).

An estimate of population size, based on BBS data, may be made by writing down an algebraic expression that describes the relationship between mean birds/ BBS route and total population size, and then estimating the terms in this relationship. This approach is followed below.

Parameter Definition

The goal is to estimate population size, defined as the average number of birds present during the breeding season in the study area. "Average" means average across the breeding season and across whatever years of data are used in the analysis. The approach is to estimate the number of males and then to divide this estimated by the estimated proportion of birds that are males, usually 0.5.

Relationship between Mean Birds/BBS Route and Population Size

A single equation could be used to describe this relationship, but for simplicity it is first presented below in four steps. The study area is partitioned into regions (i.e., strata) within which possibly different methods will be used to estimate the number of males present. We may then write (1)

$$\textit{Number of males} = \Sigma\ (\textit{Size of region})\ (\textit{Regionwide density}) \quad (1)$$

where the sum extends across all the delineated regions. Define "habitat" in such a way that all occurrences of the species are in the habitat. In the limiting case, a single habitat is defined which includes the entire study area. Many species, however, have fairly narrow and well-known habitat associations and in these cases it may be useful to incorporate habitat into the analysis. Also define "roads" as the roads used to select BBS routes and include in their definition a strip centered on the roads and extending out to the farthest distance at which the species is detected. We may then express regionwide density of males as (2)

$$\begin{pmatrix}\textit{Regionwide}\\ \textit{density}\end{pmatrix} = \begin{pmatrix}\textit{Roadside}\\ \textit{density}\end{pmatrix} \frac{\begin{pmatrix}\textit{Prop. of region}\\ \textit{that is habitat}\end{pmatrix}\begin{pmatrix}\textit{Regionwide density}\\ \textit{in habitat}\end{pmatrix}}{\begin{pmatrix}\textit{Prop. of roads}\\ \textit{that are habitat}\end{pmatrix}\begin{pmatrix}\textit{Density along roads}\\ \textit{in habitat}\end{pmatrix}} \quad (2)$$

This expression may be described by saying that regionwide density of males equals roadside density with two "corrections", the first for any difference between the amount of the species' habitat along roads and regionwide, and the second for any difference between the species' density in its habitat regionwide and along roads. For example, a woodland species might generally occur at higher densities in woods along roads than throughout the region. The second correction term in expression (2) would adjust for this difference. One advantage of expression (2) is that it describes a true

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[2]Forest and Rangeland Ecosystem Science Center, USGS, 970 Lusk St., Boise, ID 83706. E-mail: jbart@eagle.boisestate.edu.

relationship but as an initial approximation the two correction terms might be ignored (i.e., assumed to be 1.0) and then subsequent work might be undertaken to determine whether this causes significant bias in the estimate of population size.

Roadside density of males may be expressed as

$$\begin{pmatrix} Roadside \\ density \end{pmatrix} = \frac{\begin{pmatrix} Number \\ present \end{pmatrix}}{\begin{pmatrix} Area \\ surveyed \end{pmatrix}} \quad (3)$$

and the number of males present may be expressed as

$$\begin{pmatrix} Number \\ present \end{pmatrix} = \frac{\begin{pmatrix} Number\ birds \\ recorded \end{pmatrix}\begin{pmatrix} Proportion\ of\ birds \\ recorded\ that\ are\ males \end{pmatrix}}{\begin{pmatrix} Prop.\ of\ males \\ that\ sing \geq 1\ time \end{pmatrix}\begin{pmatrix} Prop.\ of\ singing \\ males\ detected \end{pmatrix}} \quad (4)$$

Expression (4) equates the number of males present with the number of birds recorded adjusted for the proportion of birds recorded that are males, the birds that are present but do not sing during the 3-min listening period, and by the proportion of the birds that do sing but are not recorded by the surveyor.

The four expressions above can be combined and written more compactly as

$$Number\ of\ males = \sum_i Ai\left(\frac{y_i}{x_i}\right)\left(\frac{m_i r_{1i} r_{2i}}{f_i g_i}\right) \quad (5)$$

where the sum extends across all of the regions and

A_i = area of region i,

y_i = number of individuals recorded in region i,

x_i = area surveyed in region i which in turn depends on the average area within which birds are audible at the BBS stations,

m_i = proportion of the birds recorded that are males,

$r_{1i} = h_{Reg}/h_{Road}$ where h_{Reg} and h_{Road} are the proportions of region i, and of the surveyed (roadside) portion of region i, covered by the species' "habitat",

$r_{2i} = d_{Reg}/d_{Road}$ where d_{Reg} and d_{Road} are the densities of the species in its habitat throughout region i and in the surveyed portion of region i,

f_i = proportion of the territorial males in the surveyed area, in region i, that sang 1^+ times while the surveyor is present, and

g_i = proportion of audible birds that were recorded in region i on the BBS.

The first two terms in expression (5) are the regionwide area and the recorded density of birds along roads. Their product may be viewed as an initial estimate of the regionwide density of males. The third term is an adjustment to this estimate to account for the proportion of birds recorded that are males, are from non-representative habitat along roads, and detection rates that are less than 1.0. In the simplest case, the five quantities in this term - m_i, r_{1i}, r_{2i}, f_i, and g_i - all equal 1.0 and the adjustment term drops out.

Interval Estimates

Expression (5) is exact; it simply provides a convenient way to express population size. All of the quantities on the right side except A_i would vary to some extent from sample to sample. With large numbers of routes surveyed and birds recorded we may assume that population size is approximately equal to expression (5) with the variables replaced by their expected values. Thus,

$$Number\ of\ males \cong \sum_i A_i\left(\frac{Y_i}{X_i}\right)\left(\frac{M_i R_{1i} R_{2i}}{F_i G_i}\right) \quad (6)$$

where the terms in expression (6) are the expected values of the corresponding variables in expression (5), with expectation being calculated across the set of possible samples that might have been obtained in region i during the years of the study. Thus, population size may be estimated using estimates of the parameters, calculated from the survey or obtained in other ways, and upper and lower confidence bounds may be obtained using statistical methods or, more crudely, by using the upper and lower bounds for each parameter if formal error estimation is not warranted.

Example

The approach is illustrated using BBS data for four shrubsteppe-obligate birds in Region 4 of the U.S. Forest Service which covers Nevada, Utah, western Wyoming, and southern Idaho. A recent GAP map has been produced for this area (*fig.1*) and an extensive accuracy assessment has been carried out (Edwards et al. 1998). Estimates of population size within this region are obtained for Brewer's Sparrow (*Spizella breweri*), Black-throated Sparrow (*Amphispiza bilineata*), Gray Flycatcher (*Empidonax wrightii*), and Sage Thrasher (*Oreoscoptes montanus*). Estimates are obtained only for the Forest Service region; rangewide estimates would require additional analyses. For convenience, the subscript is omitted below. I assumed that 50 percent of the birds are males and thus doubled the estimated number of males to obtain estimated population sizes.

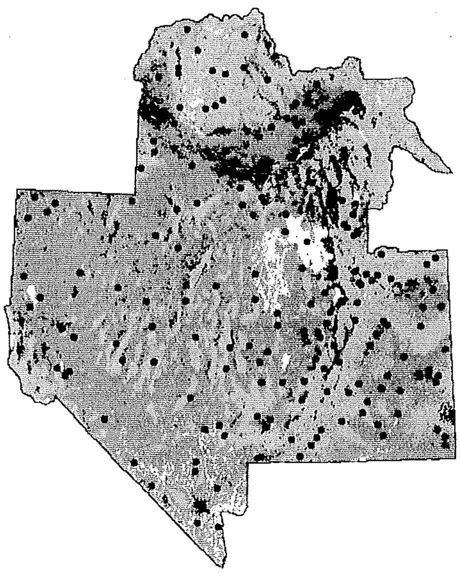

Figure 1— U.S. Forest Service Region 4. Dots indicate BBS routes; habitats are: light gray = montane; dark gray = shrubsteppe; black = agricultural, residential; white = water, missing data. Light areas southwest of Great Salt Lake and in southern Nevada are missing data.

The area, A, is 718,000 km^2. The mean number/route, y, and 95 percent confidence intervals are reported in *table 1*. The surveyed area, x, depends on the average distance at which birds are just audible. This distance could be estimated through field trials but these have not been done. Experience with the species and terrain suggests that the average is probably between 150m and 200m which corresponds to x = 3.53 and x = 6.28 km^2 per 50-stop BBS route.

The habitat term, r_1, was estimated by computing the proportions of various habitat types, as depicted by the GAP map, along roads and throughout the region. Each BBS route was buffered using a 100-m width, and the resulting polygons were intersected with the GAP map. The results showed that most shrubsteppe habitats are equally abundant along roads and regionwide (*table 2*). For example, all of the shrub steppe habitats covered 49 percent of the region and 46 percent of the roadside strips. Thus, r_1 appears to be close to 1.0. I used 0.9 and 1.1 as the lower and upper bounds.

Rotenberry and Knick (1995) studied the density of breeding passerines <25m and >400m from roads in southern Idaho. Densities were equal for Brewer's Sparrows and Sage Sparrows (*Amphispiza belli*) and slightly but non-significantly higher for Sage Thrashers away from roads. Many of the BBS routes in shrub-steppe regions are on seldom-used "two-tracks" that probably have less influence on the surrounding terrain than heavily used, paved roads. This fact and the results from Rotenberry and Knick's (1995) study strongly suggest that densities along BBS routes are similar to regionwide densities. I therefore used a range of 0.9-1.1 for r_2.

Best and Peterson (1985) and Wiens et al. (1987) studied song frequency in Brewer's Sparrows. Song frequency varied between and within years and between habitats but the average probability of singing one or more times in a 3-min period was approximately 0.4-0.6, and I therefore used this as the range for f for Brewer's Sparrows. I am not aware of similar data for the other three species, and therefore used a somewhat wider range, 0.3-0.7, for f for them.

In a simulation of singing bird surveys using tape recorded songs Bart (1985) estimated the mean fraction of audible birds recorded by 20 BBS surveyors. The mean varied from 0.63 to 0.81 among eight species, all of which were fairly common. The trials had a mean of 20 birds present which is probably higher than most BBS stations in the Great Basin, and it seems reasonable that detection rates are probably higher with fewer birds present. I therefore used 0.7 and 0.8 as the lower and upper bounds for g.

Estimated population sizes for the four species varied from <1 to about 22 million birds (*table 3*). The confidence intervals are fairly wide, but it would be relatively easy to undertake field or analytic work to narrow the ranges for y, x, m, and f, the variables known most poorly at present. Thus, this approach provides a means for meeting the recently established goal of estimating population size for many species breeding within the area covered by the BBS. Other methods, however, will be needed for northern-nesting species and species recorded only rarely on the BBS.

Table 1— *Mean birds per route and 95 percent confidence interval for four shrubsteppe species.*

Species	Mean number recorded/route	Standard error	95 percent confidence interval	
			Lower	Upper
Brewer's Sparrow	19.8	2.00	15.8	23.8
Black-throated Sparrow	9.5	1.52	6.5	12.5
Gray Flycatcher	1.5	0.50	0.5	2.5
Sage Thrasher	11.8	1.65	8.5	15.1

Table 2— *Proportion of the region and of the roadside strip covered by different habitats.*

General habitat	Specific habitat	Region	Roadsides
Montane	Forest	0.22	0.16
	Mountain scrub meadow	0.09	0.08
	Bitterbrush	0.00	0.00
	Sub-total	0.31	0.24
Shrubsteppe	Blackbrush	0.03	0.04
	Creosote-Greasewood	0.04	0.03
	Mixed scrub	0.02	0.01
	Sagebrush	0.12	0.10
	Sagebrush steppe	0.14	0.13
	Salt desert scrub	0.14	0.15
	Sub-total	0.49	0.46
Grassland/agriculture	Grassland	0.05	0.06
	Agriculture	0.06	0.12
	Sub-total	0.11	0.18
Other	Dune/lava flow	0.03	0.01
	Water	0.02	0.01
	Wetlands/riparian	0.01	0.03
	Residential	0.01	0.01
	Sub-total	0.07	0.06

Table 3— *Estimated population sizes of four shrubsteppe passerines in Region 4 of the U.S. Forest Service.*

Species	Lower bound	Upper bound
Brewer's Sparrow	3,700,000	22,200,000
Black-throated Sparrow	1,300,000	12,200,000
Gray Flycatcher	99,000	900,000
Sage Thrasher	1,700,000	15,900,000

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